NASA TECHNICAL TRANSLATION   NASA TT F-14,206

REFLECTIONS ON THE SOVIET SUPERSONIC AIRLINER TU 144

P. Bork

APR 1972
RECEIVED
NASA STI FACILITY
INPUT BRANCH
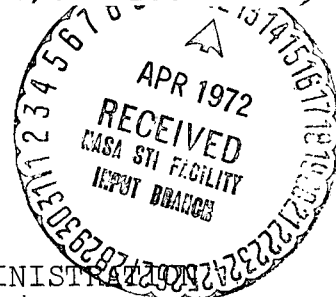
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546   MARCH 1972

REFLECTIONS ON THE SOVIET SUPERSONIC AIRLINER Tu 144

P. Bork

ABSTRACT.   The problems encountered during the design of the Tu 144 are considered. The cruising speed was limited to a range from 2300 to 2500 km/hr in order to avoid the great expenses inherent in the development of an aircraft based entirely on titanium alloys. The selection of the jet engine type is discussed together with the aerodynamic characteristics, stabilization and control, the aerodynamic design of the propulsion system, the wing structure, the landing gear, and the operation of the aircraft.

1. Design Problems of the Tu-144   /397*

The building of a supersonic transport aircraft represents true pioneering work. It is well known in specialists circles that many of the problems associated with the production of a transport aircraft did not have to be solved in military aviation. Therefore no defensive aircraft presently exists which could compete with the Tu-144 in range or uninterupted operation at supersonic speed.

The design work for the Tu-144 started in 1963 and was transferred to a working group under the direction of Professor

---

* Numbers in the margin indicate the pagination in the original foreign text.

A. A. Tupolev, the son of the well known engineer and member of the Academy A. N. Tupolev. At this time, it had already been established that the cruising speed of the aircraft would be above Mach 2. Profitable operation is not possible under this limit and it is not possible to obtain a range above 4200 km. Over 50% of all t-km performance is done with ranges between 4000 and 6500 kilometers in commercial aviation. The upper limit of range for supersonic aircraft is therefore 6800 kilometers at the present time.

The aerodynamic heating of the aircraft surface represents /398 another criterion. Conventional aluminum alloys can be used up to Mach 2.2 - 2.4, and certain parts of the aircraft must already be made of titanium alloys. The temperature of the aircraft surface is 120 - 150°C in this case (see Figure 2). If titanium alloys are used after Mach 2.4 (because of the high specific strength at temperatures up to 320°C), it turns out that a velocity below Mach 3 again becomes inappropriate. The fabrication of an entire aircraft out of titanium alloys is a completely new problem for manufacturing technology and will increase the manufacturing costs drastically. In addition to estimating the development time and development costs, the cruising velocity was established on the basis of a very simple argument. For a range of 6500 kilometers, a Mach 2.2 aircraft saves 4.5 hours compared with conventional aircraft. For a Mach 3.0 aircraft, this savings is only 50 minutes more (see Figure 3). This small savings must be paid for with three times the development and manufacturing costs. Even though a Mach 3 aircraft will undoubtedly be built, it is a good idea to pay for part of its development costs using the experience gained with a Mach 2.2 aircraft. This is why AEROFLOT as well as the aircraft industry of the Soviet Union decided on a cruising velocity
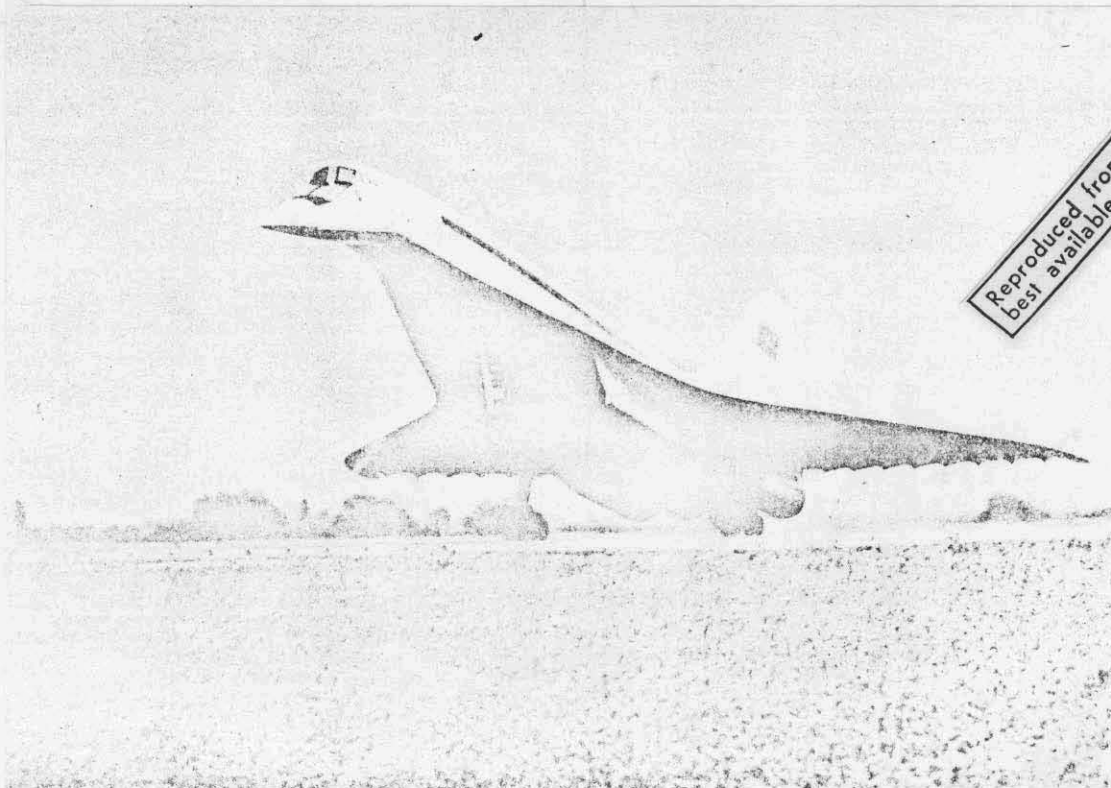
Figure 1. Tu-144 during takeoff at the
central airport Berlin-Schonefeld.
(Photograph: Willman)

between 2300 and 2500 km/h for the Tu-144. (Approximately Mach
2.2).

The crusing altitude was initially determined so that the
efficiency of the engines would be as great as possible, so that
the ascent and descent times represented a justifiable fraction
of the travel time and so that the acoustic pressure of the
compression shock would not exceed a justifiable intensity level
on the Earth's surface (7.5 - 9.2 kp/m^2). At the same time,
dangerous flight altitudes due to high energy radiation and
possible accumulation of ozone would have to be avoided. The
Tu-144 will fly at altitudes between 17 and 21 kilometers in
the future. These flight altitudes have already been sufficiently
researched and are well known. They also have the advantage that
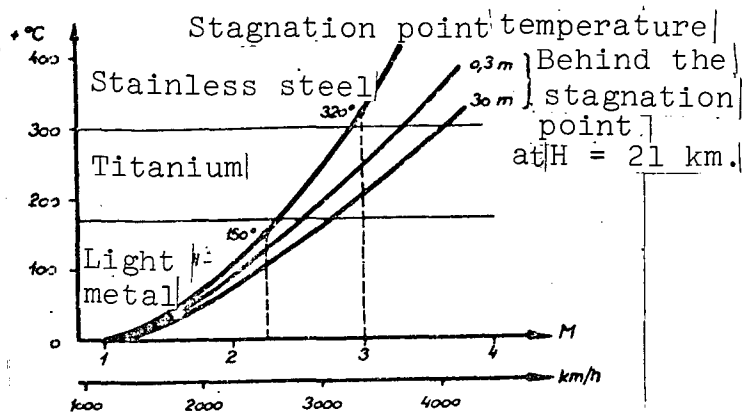
/399

3

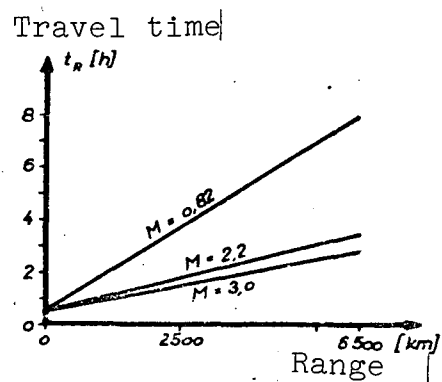Figure 2. Temperature conditions during high speed flight.

Figure 3. Dependents of the travel time on half-length and velocity for cruising flight.

navigation along the shortest distance between two points on the Earth's surface is not restricted to narrow flightpaths.

The selection of the engines was preceded by numerous investigations of the efficiencies of modern engines. Ducted-fan engines, turbo jet engines and turbo jet engines with afterburners are possible candidates. In contrast to conventional aircraft, the SST aircraft must produce maximum thrust during takeoff as well as during other flight regimes. Investigations showed that there is no single engine which could be used in the entire velocity range of the supersonic aircraft (see Figure 4). The ducted-fan jet engine has not yet been sufficiently investigated in the supersonic range, and is also less efficient than the turbo jet engine with afterburner (TLF) in the supersonic range. In addition, it has a considerably higher frontal resistance. The turbo jet engine with afterburners has very large thrust reserves in ascending flight and during the transition phase, where it is flown with the full afterburner. During cruise, the afterburner is throttled down to 30 – 40% of its performance. Of course the specific fuel consumption increases as the velocity is increased (an increase of 45% from Mach 0.8 to Mach 2.2). But the thrust increase brought about by a
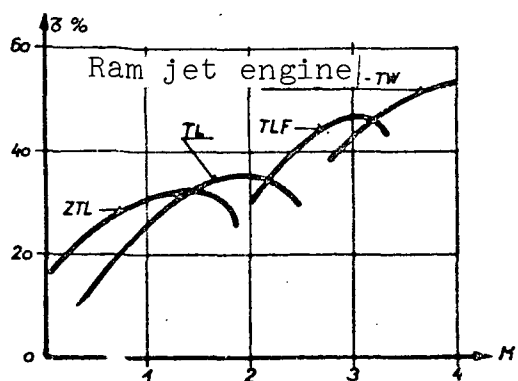
4

Figure 4. Efficiency of
  various engine types as
  a function of velocity.
ZTL: Ducted-and turbo jet
TL turbo jet
TLF: Turbo jet with after
burner.

velocity increase is considerably higher, so that overall the efficiency of the engine improves as velocity is increased. All of these factors and the experience over many years with the engine of the Tu-144 in defensive military aircraft led the designers to select a turbo jet engine with afterburners for the Tu-144. It is a three shaft engine with a six cascade afterburner and an initial thrust of 17.5 Mt.   /400

2. Particular Aerodynamic Features of Supersonic Aircraft.

The particular external form of the Tu-144 as compared with conventional jet aircraft can be explained on the basis of efficiency, and not on the basis of aesthetic sensitivity of the designers. An aircraft shape must be found which has the highest possible lift and the smallest possible drag. The following types of aerodynamic resistance determined the external shape of the supersonic aircraft:

a) Wave drag comes about due to compression shocks of the air stream at all parts of the aircraft which protrude into the flow as well as along the lifting surfaces and at the air intakes. The production of the compression shocks is an immediate consequence of the supersonic velocity of the aircraft and is associated with considerable energy loss. In order to reduce the wave drag, the following measures are employed:
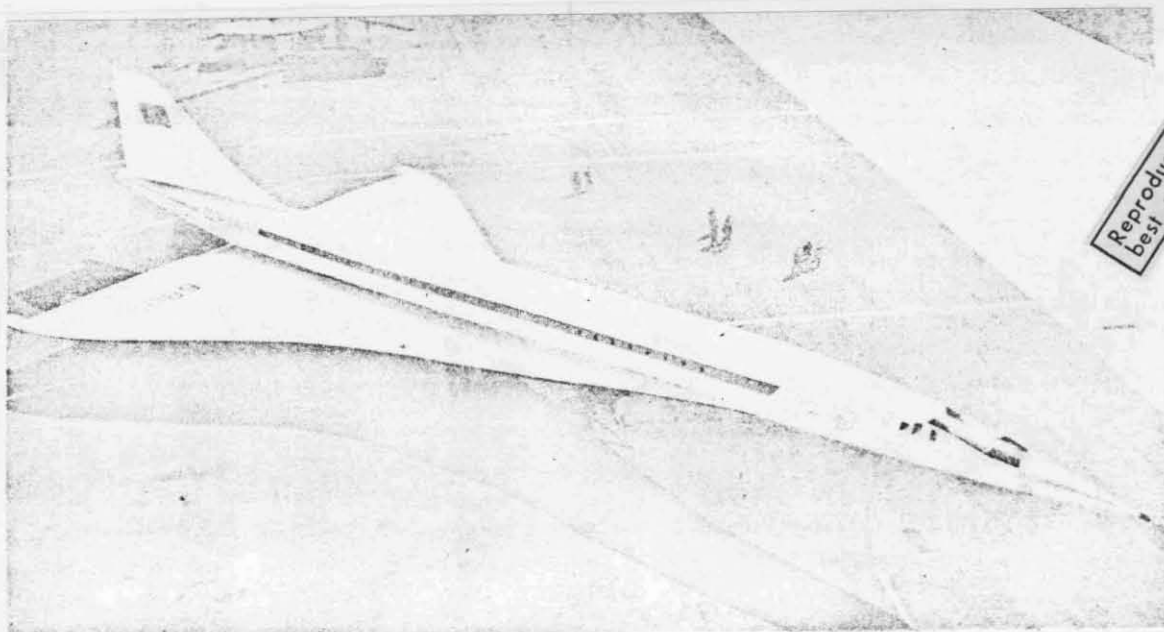
Figure 5. Supersonic transport aircraft
Tu-144 (Photograph: Noppens).

The lifting surface leading edge is swept back considerably
(56-78° in the case of the Tu-144);
the wing thickness is 2.5 - 3.5% of the profile depth (this
amounts to 0.6 m at the height of the main landing gear wheels
in the case of the Tu-144)
and is therefore considerably lower than in conventional air-
craft;
The ratio of the fuselage diameter to the free fuselage forebody
$\frac{L_o}{D}$ (see Figure 6) must be at least 6.0 (Tu-144: prototype
$\approx$ 4.8; series production aircraft $\approx$ 6.2;
The ratio of the fuselage diameter D to the span b should not
amount to more than 0.15 (Tu-144 $\approx$ 0.13);
The angle range of the wing ω (see Figure 6) should be smaller
or equal to the aperture angle of Mach: d at maximum velocity
(Tu-144:$\omega \approx 16°$, $\alpha \approx 25°$);
Also the wing aperture angle γ (see Figure 6) should be smaller
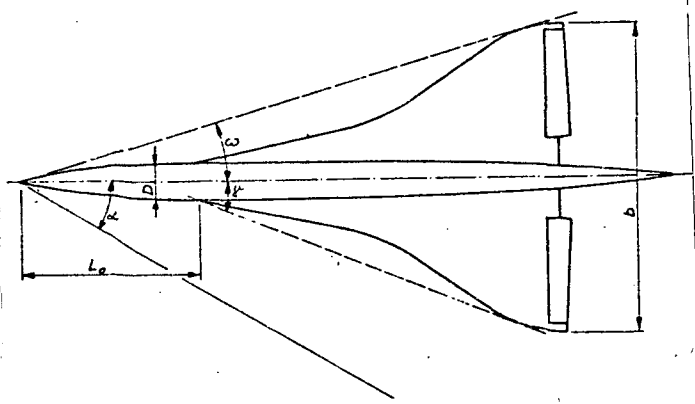or equal to α (Tu-144: $\gamma \approx 21°$).

Figure 6. Explanation of the
    aircraft configuration.

b) The friction drag is brought about by friction of the aerodynamic stream at the aircraft surface. The rivets and skin discontinuities must be perfectly machined in the |case of a supersonic aircraft. In this regard, the Tu-144 represents an excellent piece of work of the soviet aircraft builders.| The fuselage is very long| but| does not have a laminar shape. Instead, the diameter is reduced /401 towards the tail. This shape means that the area rule is observed. The area rule says that supersonic aircraft must have a cross section so that its projection on the aircraft logitudinal axis is favorable for the flow. In order to induce the friction drag of the lower side of the fuselage, there is a boundary layer barrier above the air intake opening. This brings about an acceleration of the flow adjacent and below the fuselage, which causes a reduction in the wave drag. In regions where the sweepback of the main wing is low, there is a very sharp profile leading| edge, which has the overall affect of reducing the profile drag considerably.

c) The induced drag is brought about by pressure equalization between the lower and upper surfaces of the wing. It develops| in the form of an edge vortex along the entire outer edge of the wing, especially in the outer region. Figure 7 shows a flat delta wing, for which there is a continuous| increase in the pressure distribution between the upper and lower sides along the
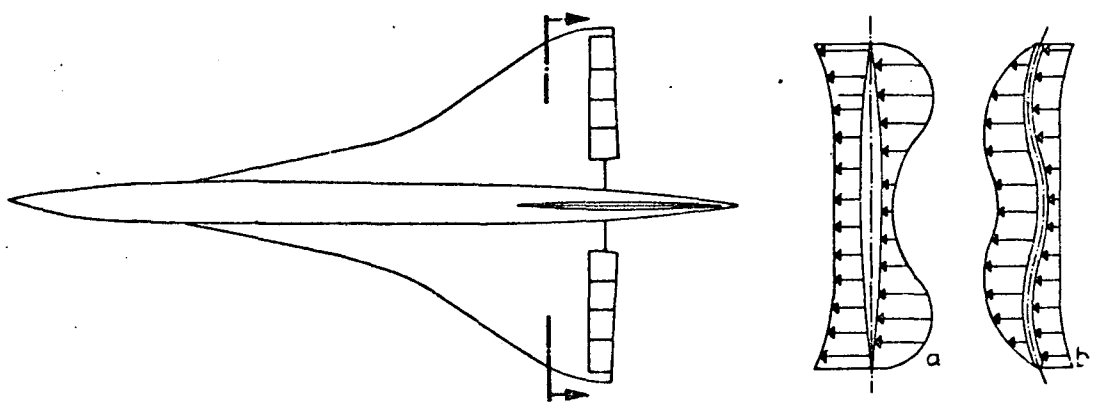
7

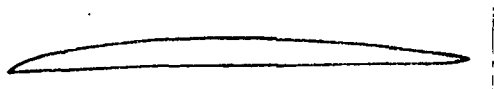Figure 7. Influence of the cross wind on the lift distribution of the delta wing.

Figure 8. Special wing shape of the Tu-144 and almost flat profile lower side and approximately symmetricly curved upper side.

outer edge. The edge vortex and therefore the induced drag are especially large there. The rounded delta wing, on the other hand, which has a rounded edge (see Figure 7 b) reduces this pressure difference considerably. This is why the Tu-144 has a highly curved intermediate wing section which is very thick at the tip. The intermediate wing section is almost completely in the subsonic region and prevents the separation of strong edge vortices in the central region of the wing. At the same time, it stabilizes the wing flow and increases the aerodynamic quality of the wing.

d) The balance drag is caused by the required rudder deflection. The Tu-144 was designed so that the balance drag would be as small as possible during cruise conditions. A wing
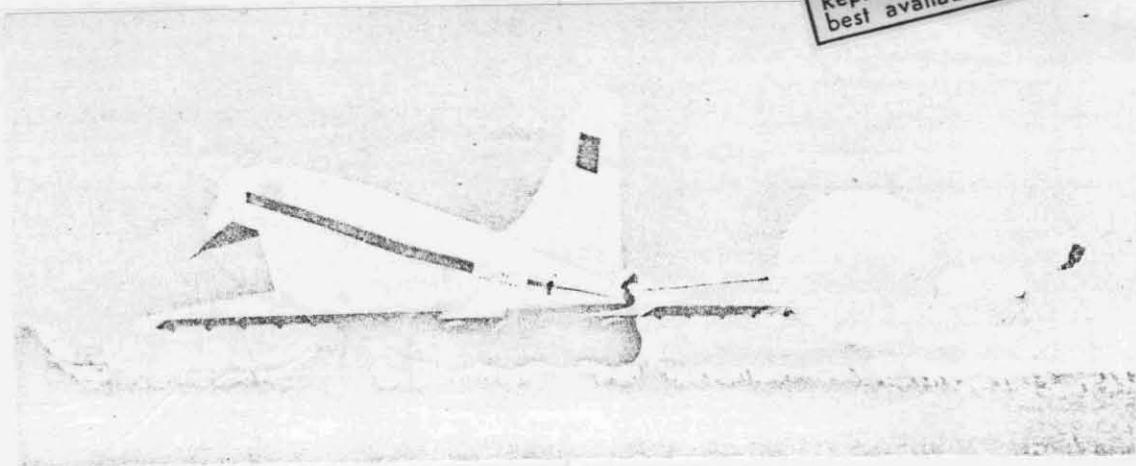
Figure 9. Tu-144 during landing with
braking parachutes (photograph:
Willmann)

shape has to be found for this purpose which would produce a
sufficiently high pitching moment around the transverse axis
(see Figure 8). The wing of the Tu-144 is almost completely
flat along the lower side of the profile. The upper side has a
curvature which is almost symmetric. This profile means that the
center of gravity is far back, which reduces the deviations of
a neutral point and brings about over-stabilization in the
subsonic range. This profile shape is connected with a twisting
of the wing, where the angle of attack decreases at the outer
regions of the span. The twist and profile shape are selected
in such a way that there will be an optimum angle of attack of the
aircraft during cruise without any rudder deflection. In order to
maximize the range, control is effected by means of a thrust
vector and not by using the rudders. Depending on the atmosphere
conditions, the velocity is selected so that the aerodynamic
quality is optimum. This task is performed by means of a
velocity control automatic system, which also simplifies flying
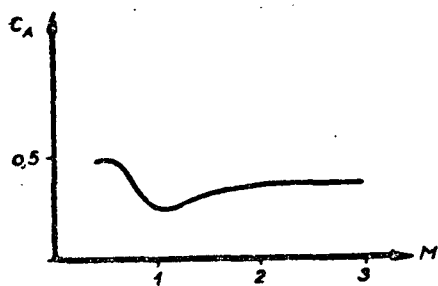of the airplane.

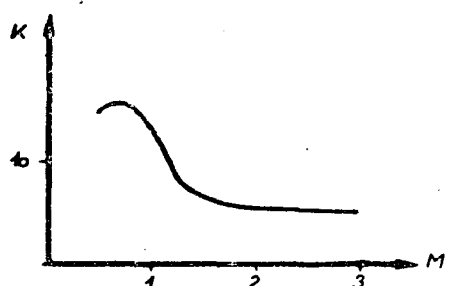Figure 10. Dependence of the lift coefficient on the Mach number.

Figure 11. Dependence of the aerodynamic quality on the Mach number.

The lift coefficient as well as the aerodynamic quality[*] are considerably reduced under supersonic flight conditions. One important task of the aerodynamicists is to improve the aerodynamic quality — that is, the ratio of the lift coefficient to the drag coefficient — using any available means. Figure 11 shows that there is an enormous reduction in the quality[*] coefficient for supersonic flight conditions. At the same time, the range is considerably reduced and the fuel consumption increases. The quality[*] factor was increased by the designers of the Tu-144 by means of the following measures: /402

1. The drag of the aircraft was reduced by any means which could be justified from a production point of view;

2. The wing was twisted in the transverse as well as in the longitudinal direction. This brought about an improvement in the quality[*] factor as compared with conventional delta wings, as is shown in Figure 12. The improvement amounted almost to a factor of 2.
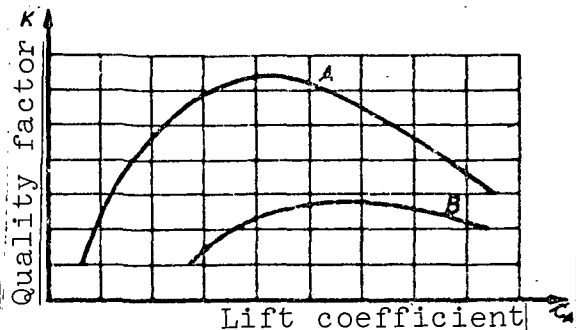
---

*Translator's note: This is the lift-to-drag ratio.

Figure 12. Influence of the
lifting surface shape on the
quality factor.
A - stabilized twisted lifting
surface with alternating sweep-
back.
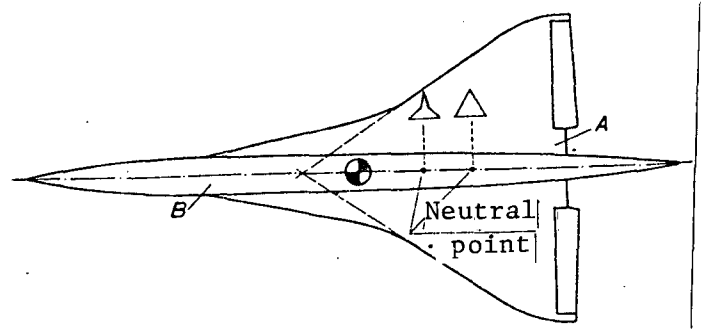B - stabilized flat delta wing.

Figure 13. Displacement of the
neutral point due to the
wing filling section B.

3. The sweep-back of the wing of the Tu-144 changes. This
contributes to an improvement in the quality factor during
cruise. The very large delta surface as well as its aspect ratio
$\lambda = 2$ means that the induced drag can hardly be reduced any more.
However, the lift coefficient is sufficient for a landing (angle
of attack during landing is about 14°).

4. The lower side of the fuselage is included in the
overall wing configuration. The fuselage generates a lift even
for small angles of attack under supersonic flight conditions.

3. Stabilization and Control of the Aircraft.

Not all supersonic aircraft must have the appearance of the
Tu-144. However, the nature of this aircraft has been dictated
by several conditions of supersonic flight. Probably the most
important problem consists of the "neutral point dispersion".
Aerodynamicists refer to the neutral point as the point along the
profile axis for which the overall aerodynamic moment is
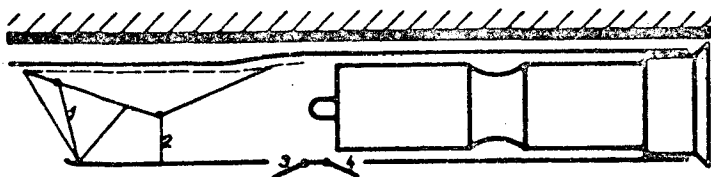independent of the angle of attack. If this point is displaced,

11

Figure 14. Principle of the
  air combustion chamber.
  1 - oblique compression shock;
  2 - normal compression shock;
  3 - incoming flow flap;
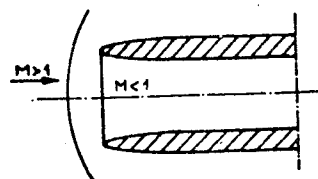 4 - overflow flap.

Figure 15. Simplest air intake
  with upstream compression
  shock.

then the pitch restoring moment is increased and the effect of
the elevator is reduced. In order to maintain controllability,
the distance between the center of gravity and the neutral point
of the aircraft must be maintained inside certain limits. The
center of gravity is placed close to the neutral point in order
to bring this about. This reduces the neutral point displace-
ment.

     What did the designers of the Tu-144 do in regard to this
problem?

     a) An integral tank was installed in the rudder assembly.
Fuel is pumped from the most forward fuel tanks into the tank in
the rudder assembly as a cruise velocity is approached. In
particular, this is done during the transition phase (flying
through the velocity corresponding to Mach 1). This is the   /403
only way that the center of gravity can be displaced. Because
of the selected wing shape, profile form, and configuration of
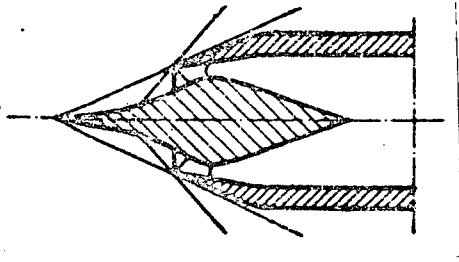the available spaces of the fuselage, the center of gravity is

12

Figure 16. Air intake with
central body adjustable in
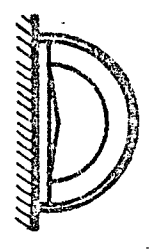the longitudinal direction.

Figure 17. Semicylindrical
air intake with one-half
of the central body
located on the side of
the fuselage.

already considerably displaced towards the rear. An onboard
computer installation controls the fuel consumption and the fuel
displacement by giving appropriate commands to the pumps.

b) The wing shape contributes to a reduction in the neutral
point displacement. Figure 13 shows that the Tu-144 has two
wings which are effective in different ways. The subsonic
wing consists of the main wing A with a small sweep-back. The
supersonic wing is made up of the delta-shaped main wing A and
the intermediate wing section B. The intermediate section has
such a strong sweep-back (about 72°) that it has almost no
aerodynamic effect during slow subsonic flight. Since the
position of the neutral point is always determined with repect
to the overall effective wing, the neutral point of the area
A + B is always ahead of the one for area A. Thus, the
displacement of the neutral point of surface A is compensated by
the new position of the neutral point of the surface A + B
during supersonic flight.

c) The aerodynamic shape of the aircraft was selected
so that the Tu-144 can maintain the necessary attitude during
cruise without reducing stability. Depending on the reduced
mass of the aircraft during flight, the distance between the
center of gravity and the neutral point is selected in such a
way that the aerodynamic quality is the highest. The center
of gravity of the aircraft must be slightly displaced during
the supersonic flight phase.

One peculiar aspect of the Tu-144 is the fact that there is
no elevator on the fuselage. The rudders at the trailing edge
of the wing are sufficiently far removed from the center of
gravity of the aircraft in order to be effective. The rudder
surfaces (4 sections on each side) are used as elevators and
ailerons. Their size is determined by their normal depth
with respect to the profile length and also because they must
extend beyond the turbulence layer, within which they are not
effective as control members, during the transition phase.
This turbulence layer is brought about by boundary layer
separation due to compression shocks on the upper and lower
side of the wing (especially in the velocity range corresponding
to Mach 1).

The stability of the aircraft during landing is greater than
for conventional aircraft. Since the delta wing reaches the
highest lift coefficient value at almost twice the landing
angle of attack, there is no danger of flow separation. The
size of the wing considerably exceeds the required area for
slow flight, which means that a landing velocity of 260 km/h
can be reached with an angle of attack between 12 and 14°. /404
This velocity corresponds to that of heavy aircraft at high
subsonic speeds (for example IL-62), which still however have
lift increasing devices along their wings. The Tu-144 has no

14

mechanical devices for increasing lift during slow flight.
The landing approach is carried out at the same angle of at-
tack as the landing itself. An air cushion develops as the
ground is approached, which attenuates the vertical velocity
down to 0 m/s and which produces an increased pitch moment at
the same time. The pilot equalizes only this moment with the
rudder and therefore maintains the angle of attack constant.
There is a vertical indication device located between both
pilots on the cockpit windshield. It is used to display the
angle of attack, which becomes critical at 16° because at
this angle the engine tubes touch the ground. If this critical
value of the angle of attack is reached just before touchdown,
the aircraft pitches down automatically and stabilizes itself
by means of a greater pitching moment.

4. Aerodynamic Configuration of the Engine Tract.

The performance and efficiency of an engine depends
considerably on the maintenance of energy during impact ram
compression. The kinetic energy of the incoming air must be
transformed into a stagnation pressure increase as completely
as possible during the deceleration process in the air intake.
It is the purpose of the air intake to decelerate the air
coming in at the flight velocity down to subsonic velocity.
There exist no engines in which the energy could be added to
the airstream at supersonic velocities. The engines of the Tu-
144 do have a first stage in the compressor with supersonic
blades. However, the engine does operate with subsonic flow.
The braking of velocity can only be carried out by means of a
system of several compression shocks. In principle, this
could be done by means of two or three additional air intake
shapes. The intake channel (Figure 15) which is usually used
near subsonic speeds could / also be used for supersonic speeds.

The compression shock then emerges from the intake and increases the drag up to a large and unnecessary value. Because of the losses, the aircraft could not be operated economically under these conditions. Therefore, stable operation of the engine could hardly be achieved, because the turbulent nature of the airstream would influence the inlet conditions at the compressor in an unfavorable way.

Figure 16 and 17 show air intakes with a movable central body. For example, they had been designed for the American supersonic aircraft, which has been given up in the meantime. It is not possible to produce more than one oblique shock, located at the leading edge of the air intake, over a large velocity range. These highly effective air intakes with central body (Figure 18) also require individual suspension of the engines, which is aerodynamically less favorable (Figure 19).

The air intake selected for the Tu-144 offers the best aerodynamic possibilities. The stagnation pressure increase is about a factor of ten in it and is relatively independent of the angle of attack. The engine itself requires about 1/3 of the tract length. The other two thirds are required for the formation of the diffusor, in particular for relaxation of the air after passing the smallest cross section in which the normal shock is located (see Figure 20).   /405

The air intake is one of the most important design problems of a supersonic aircraft. It must produce approximately 3 and one-half times the air mass in supersonic flight with low losses, while the input conditions to the compressor remain constant. It is automatically controlled by measuring the air pressure in front of the intake and at the position before and behind the normal shock. The hinge between the members II
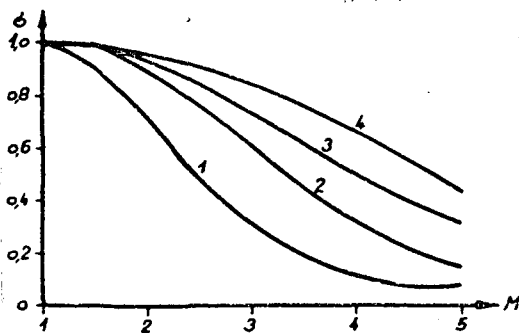
16

Figure 18. Dependence
of the pressure
recovery factor on
the system of compres-
sion shocks.
1 - upstream normal
compression shock (see
Figure 15) (at M = 2.2:
σ = 0.6)
2 - one oblique and
one normal shock
(σ = 0.85)
3 - two oblique and
one normal shocks
(see Figure 16)
(σ = 0.93)
4 - three oblique and
one normal shocks
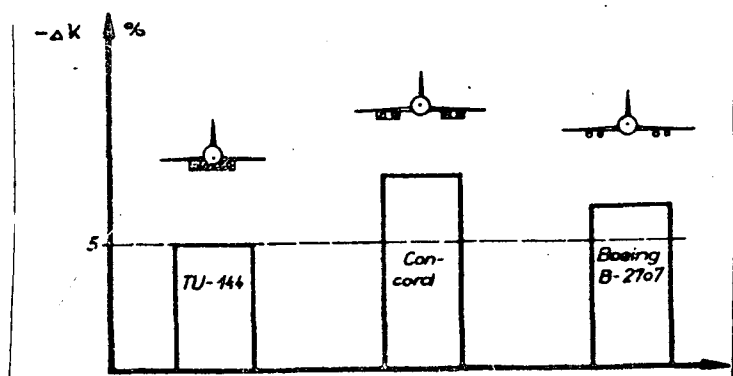(see Figure 14, Tu-144)
(σ - 0.96)

Figure 19. Loss in aero-
dynamic quality due to
arrangement of the engines.
The 2% K advantage of the
Tu-144 with respect to the
Concord corresponds to a
savings of 1 million
marks for 30000 hours of
operation.

and III of the diffusor plate
(Figure 20) represents the
critical cross section. The
diffusor plate is extended so
that the normal shock is
located exactly at the hinge.
By means of an overflow flap
in front of the engine, it is possible to expel the excess air
mass if the normal shock remains in the same position and if the
pressure in front of the engine is too high.

There is a stabilizing flap on the lower side of the air
intake at the formost point, with which it is possible to
prevent possible pulsations of the flow in the diffusor during
velocity changes in supersonic flight. The flap IV (Figure 20)
and the intake flap are opened during takeoff and slow flight,
in order to increase the effectiveness of the engine. Both
flaps can be opened during supersonic flight as necessary, in
order to have better control of the engine if a disturbance
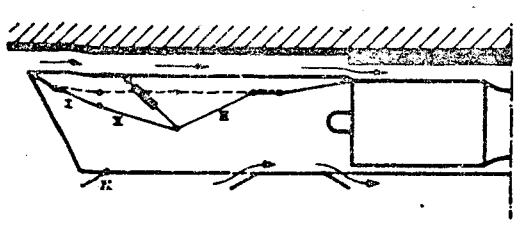
Figure 20. Air intake
   of the Tu-144
   (schematic)
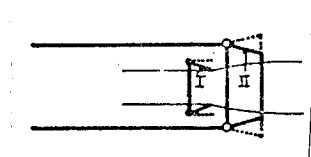

Figure 21. Thrust
   tube flap position
   for supersonic flight.
   I - flaps of the
   Laval nozzle.
   II - flaps of the
   thrust tube throttle.
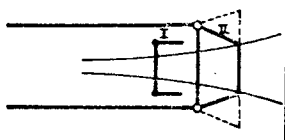

Figure 22. Thrust
   tube flap position
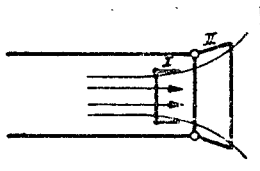   for subsonic flight.

Figure 23. Thrust
   tube flap position
   with afterburner in
   operation.

occurs. The boundary layer below the fuselage is partly deflected to the side, and partly directed into the nacelle for ventilation.

The thrust tube is used to convert the heat energy added in the engine into kinetic energy. At the end of the thrust tube, the expansion amounts to a factor of 20 - 30. Only the smallest part of this expansion (approximately 25%) occurs in the turbine. The gases leave the turbine under high pressure (it produces the thrust), which must be expanded down to atmospheric pressure at the end of the thrust tube. During this process, /406 the velocity in the gas stream is increased to several times the speed of sound. If atmospheric pressure is not reached at the end of the thrust tube, considerable energy losses occur. These are brought about by means of compression shocks, which theoretically can be avoided, in the thrust stream and amount to about 14% for Mach 2.2.

Figure 21 shows the double thrust tube flap system of the Tu-144. The flap ring I forms the critical Laval nozzle cross section, in which the speed of sound is reached. The flaps of the thrust tube throttling are important during subsonic flight as well as for operation of the afterburner. On the one hand, the thrust tube throttle flap makes it possible to change the thrust at the same velocity and to better match the work of compression with the work in the turbine. On the other hand, this flap ring is necessary in order to change the cross section when the afterburner is switched on. The afterburner of the Tu-144 operates during the take-off phase as well as during the cruise phase (see Figure 23).

The size of the cross section is adjusted according to the degree of expansion, that is, according to the ratio between the pressure behind the turbine and at the end of the nozzle. If it is desired to have atmospheric pressure at the end of the thrust tube because of the improved efficiency, then a definite cross section must correspond to each engine operation regime. Figure 24 shows the ratio F_{II} / F_I (see Figure 21) as a function of Mach number. Whereas the cross section I decreases as the flight velocity is increased, the cross section II must increase. The cross section is controlled automatically. By measuring only a few parameters, (pressure, velocity, temperature) the automatic control system, which is connected with a computer, can adjust to the required values for the two nozzle cross sections. The automatic control system is coupled with a velocity stabilization control system.

5. Description of the Construction.

Main plane structure: the main plane structure as well as the entire cell construction is made of an aluminum alloy which
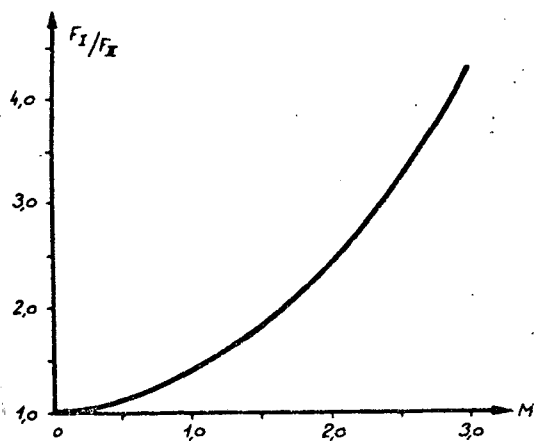
Figure 24. Cross section
change in the thrust
tube as a function of
flight velocity.

is especially temperature
resistant (see Figure 2).   /407
The wing shape is in the form
of a triangle, and is in the
form of a delta wing with two
angles of sweep-back with a
main wing and a wing intermedi-
ate section. The main wing
section has twist in the
longitudinal and transverse
direction. Only the main wing
has a pointed profile leading
edge. The intermediate wing
section has a relatively large thickness and a strongly curved
profile nose. The fuel tanks are all in the form of integral
containers and are distributed over the entire main wing (approx-
imately 100,000 liters).

Fuselage: The fuselage has a cylindrical shape and is made
up of two radii in the forward section. The lower part of the
fuselage up to the engine intakes is almost flat. The fuselage
diameter is continuous only in the central part and is reduced
towards the front and rear. The pressurized part of the fuselage /408
has a length of 40 meters and extends from the cockpit to behind
the end of the thrust tube. The fuselage nose can be dropped
electrically and is outside of the pressurized part. The
length of the series produced aircraft is 6 meters longer than
in the case of the prototype, so that now 150 instead of 120
passengers can be transported in the prototype. Only the first
and second pilot together with the ejection seats were installed
in the cockpit of the test aircraft 68001. The onboard engineer
as well as the test flight engineer, who will not be present in
the series produced aircraft, at present sit in a modified

20

first class lounge, that is, behind the front door. They also
have ejection seats. The onboard engineer sits perpendicular to
the flight direction behind the second pilot in the series
produced aircraft. The length of the commercially useful
fuselage section is 42 meters in the series produced aircraft,
including a baggage area which is 6.7 meters long. In the
series produced aircraft, the baggage area can be reached
through a container opening, which the prototype already had.
The fuselage has two entrance doors which open to the outside
and two emergency exits on both sides of the wing.

In the nonpressurized part of the tail there is an
auxiliary turbo charger unit for compressed air used for
starting the engines, which is installed perpendicular to the
fuselage. It is also used for cabin air-conditioning on the
ground and for producing electrical energy. In addition, the
prototype has braking parachutes which are located in a container
in the fuselage tail.

During flight, the fuselage is air-conditioned by cooling
the air in several stages. The air taken from the engines is
cooled in an air-air heat exchanger using air from the intake
tract. It is then cooled to approximately 120° C in a fuel-
heat exchanger using fuel. Finally it is expanded in a turbo-
cooler to about -40° C. This air is then directed along the
fuselage surface from the upper side of the fuselage. It then
enters the cabin through porous cabin walls. The temperature   /409
in the cabin can be controlled between 18-25° C. Part of the
tract air is also directed into the fuselage in order to
control the interior temperature. The air passes through the
bottom of the fuselage, through the landing gear tracts and into
the atmosphere. Even though the surrounding temperature is -60°C,
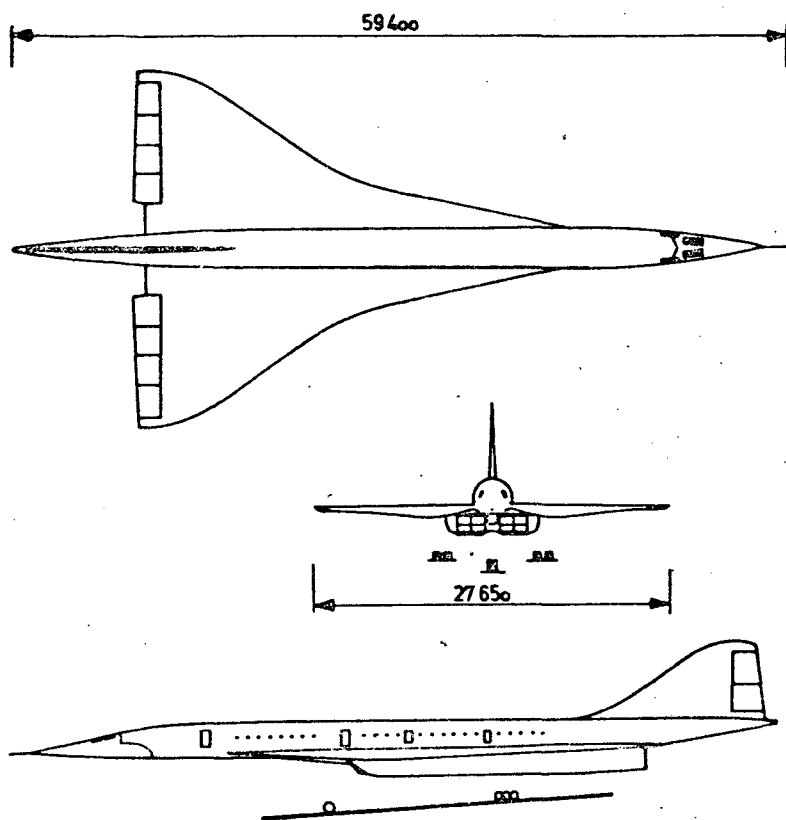the fuselage and wing surface temperatures are between +100 to

Figure 25. Three views of the
  Tu-144.

+120° C. Normal life could not be sustained in the cabin without the cooling from the inside of the fuselage.

Tailplane: The tailplane consists of side surfaces with the rudder and the elevators. The side rudder has two sections which are operated by means of two boosters[1], which can be activated by four independent hydraulic systems. Even if only one hydraulic system operates, 50% of the boosters will still operate and can operate the rigidly connected sections. The four sections of elevators on each side of the wing act as ailerons and elevators and are independently controlled through two command systems. The sections are also rigidly connected and are operated together during each flight phase. Two boosters operate each section, and only one is necessary for operation. Each booster is supplied

---

[1] Booster-hydraulic amplifiers, which hydraulicly amplify the control signals of the pilots and which are transferred to the rudders. The control does not operate in a reversible manner, which means the steering pressure must be imitated by means of a special device.
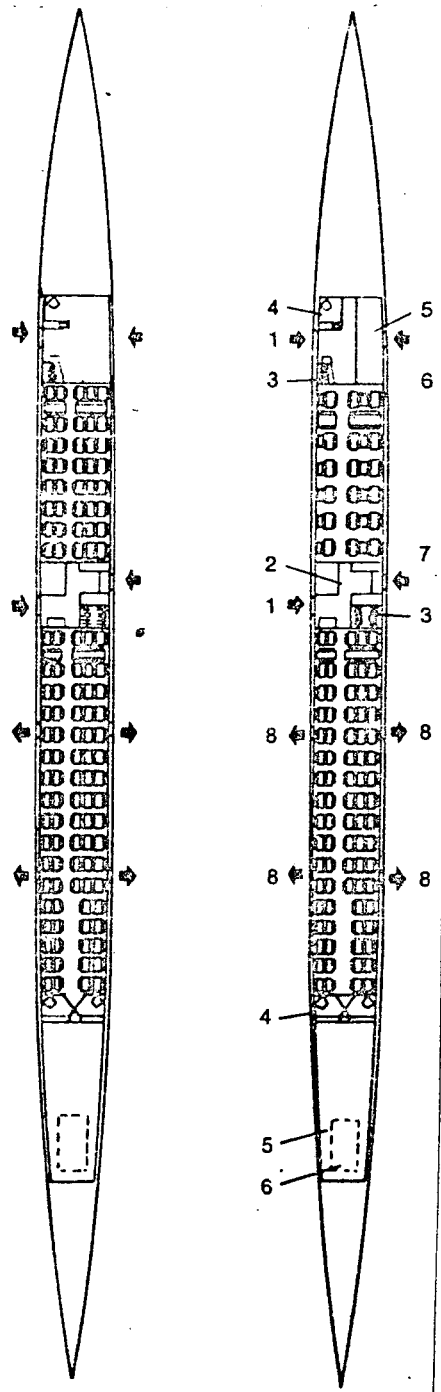
Figure 26. Cabin arrangement for tourist version with 120 seats and combined variation with 98 seats (18 first class seats and 80 tourist class seats)

by two of the four hydraulic systems. The aircraft does not have additional aerodynamic flaps, spoilers or canard wings.

Landing gear: The landing gear is of the 3 point type and had to be designed considering the fact that the relatively thin wing offers relatively little space for pulling in the wheel car bodies. This is why the relatively small diameter of the tires (about 0.8 meters) is noticeable. Each of the main landing gear assemblies have six wheels with twin tires. There is a ventilator for cooling the disc brakes in each wheel, which operates for a certain time after landing. A tire pressure of 13 at was selected because of the small size of the tires. Nitrogen is used to fill the tubeless tires. The nose landing gear has two wheels, which can be turned in the range ± 60°. The nose landing gear is pulled into the fuselage

between the air intake tracts. The main landing gears are
tipped forward into the wings. The landing gear flaps protrude
somewhat out of the wing contour.

6. Operation and Equipment.

The fact that the crew was limited to three persons made
it necessary to extensively automate the piloting of the air-
craft. Even a larger crew could not solve the novel problems
if the tasks were distributed in the usual way. The velocity
of the aircraft means that many calculations, control functions
and operations cannot be carried out manually. The first pilot
is also the radio-man. The second pilot is also the
navigator. The onboard engineer monitors especially the
fuel system, deicing, air-conditioning, electrical power and
the engines.

One of the important new features of the navigation
equipment is the inertial navigator with Doppler radar
correction. With the installation it is possible to preprogram
seven flight path segments, to project maps with scale selection,
to display the location of the aircraft and to represent the
elapsed flight path in the orthogonal coordinate system. In
addition, the map of a destination airport with flight
approaches can be projected and can be automatically flown.   /410
The required frequencies for guiding flight paths, flight path
and distance measurement to five airports can be programmed
using a frequency register. The ground system used in the USSR
or in any country can be selected by means of a switch.

In addition to the autopilot used for automatic landing
down to touch-down and the corresponding operational devices,
there is an automatic system for velocity control with an

24

accuracy of ± 10 km/h. The autopilot can also be used to automatically control the thrust during descent. About 17 minutes are required to reach the 17,000 meter cruise altitude, for which a distance of 300 kilometers is required.

7. Other Data.

Length approximately 59.4 meters (series produced aircraft 65 meters)
Span 27.65 meters
Height 11.2 meters
Fuselage length without nose 51.2 meters (Series produced aircraft 57 meters)
Wheel separation 13.8 meters
Wheel base 7.8 meters
Wing surface approximately 395 m^2
Side control surface approximately 54 m^2
Fuselage height about 2.7 meters
Fuselage width about 3.2 meters
Door height, rear cabin 4.4 meters
Eye level of the pilot during landing 11.6 meters
Sweep-back of the main wing 56°
Cruising velocity 2300 - 2500 km/h (Mach 2.2)
Approach velocity 290 km/h
Landing velocity 260 km/h
Landing roll distance 1200 m
Takeoff rolling distance 1900 m
SLB length (ICAOO) 2800 m
Maximum takeoff weight 170 Mp (Series produced aircraft)
Maximum takeoff weight approximately 150 Mp (Prototype)
Empty weight about 75 Mp (Series produced aircraft)
Fuel load 80 Mp
Number of passengers, Max. 150

Baggage room area about 15 m^2